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ABSTRACT

We report the first observations of the 51.8μ fine structure transition $p^2 : {}^3P_2 \rightarrow {}^3P_1$ for doubly ionized oxygen. The observed line strength in the Orion Nebula is $5 \pm 3 \times 10^{-15}$ watt cm^{-2} in good agreement with the theoretical predictions of Simpson (1975). Our observations also are consistent with the newly predicted line position, 51.8μ . The line lies close to an atmospheric water vapor feature at 51.7μ , but is sufficiently distant so that corrections for this feature are straightforward. Observations of the 51.8μ (O III) line are particularly important since the previously discovered 88μ line from the same ion also is strong. This pair of lines should therefore yield new data about densities in observed H II regions; or else, if density data already are available from radio or other observations, the lines can be used to determine the differential dust absorption between 52 and 88μ in front of heavily obscured regions.

Introduction

During the past few years, infrared spectral observations at medium resolution have become possible in the 100μ wavelength region of the far infrared. This has led to the discovery of a number of spectral lines that had originally been predicted by Petrosian (1970). Petrosian had pointed out that fine structure transitions of singly or multiply ionized atoms in H II regions should yield an appreciable far infrared flux. Simpson (1975) repeated these calculations with somewhat better data that had become available in the intervening years, and was able to provide predictions for line strengths which--at least for the (O III) line at 88μ --are in remarkably good agreement with observations on a number of H II regions (Dain et.al., 1978, herinafter referred to as Paper I).

Despite the discovery of several different infrared emission lines in H II regions, one difficulty in the interpretation of data has been the lack of more than one infrared line, from any individual ionic species. While both visible and infrared data exist for many of the ions--(O III) is a prime example--the comparison of visible and infrared line strengths is made difficult by the large uncertainties in the visual absorption both within the H II region and along the path lying between the H II region and the Earth. This is particularly obvious for the giant H II regions which are completely hidden behind dark dust clouds and yet emit the strong 88μ radiation described in Paper I.

From this point of view, one particularly interesting line to observe had generally been acknowledged to be a companion fine

structure transition of (O III) which was believed to lie near 51.7μ . The precise position was uncertain because the anticipated wavelength could only be estimated by comparing the wavelengths of ultraviolet lines originating from upper and lower levels, and these ultraviolet data seemed insufficiently precise to permit an exact estimate of the infrared line position. Such an estimate, however, was important since an atmospheric water vapor feature is known to lie near 51.7μ , and could well have absorbed all the flux emitted in the (O III) line, or at least made any interpretation of line flux quite uncertain.

Recently, however, more accurate estimates by Dr. Lawrence T. Greenberg (1977) of the University of California at Berkeley have shown the (O III) line to lie close to 51.8μ . This appeared to us to be far enough away from the atmospheric absorption line to permit successful observations. We are grateful to Dr. Greenberg for providing us with the information we needed to undertake the measurements we report here.

Observations of the 51.8μ line together with 88μ line observations should, in the long run, provide us with a variety of useful data. In H II regions where the electron number density is poorly known, a more accurate estimate should become possible since the relative line strengths of these two fine structure transitions are affected by the number density. When the number density can be determined from other data, for example through radio observations, then the relative strengths of the two lines should allow us to make an estimate of the relative amounts of far infrared absorption by interstellar dust. The far infrared

wavelength dependence of dust absorption currently is poorly understood and any information that could provide even a rough estimate of the absorption would be very useful.

Observations

Observations were carried out in almost precisely the same way as in previously reported work (see for example Paper I). The NASA Lear Jet 30 cm telescope was employed, and our liquid helium cooled grating spectrometer was used at an instrumental resolving power of about 150. The system noise equivalent power in flight is approximately 3×10^{-13} watt Hz^{-0.5}, including all losses due to the telescope, chopper and atmospheric effects.

The spectrometer's entrance slit dimensions determine our beam size which extends over a 4' x 4.4' region in the sky. The telescope's oscillating secondary mirror which chops the radiation at ~25 Hz provided a beam separation of 14'.

We observed the Orion Nebula during the evenings of December 6, 8 and 14, 1977, and detected the 51.8 μ (O III) line on all three nights. Clear air turbulence on the last of these nights, however, resulted in poorer signal to noise ratios for that night than for the others. Even on the night of December 14, however, there is no question at all that the 51.8 μ line was present in the strength reported. Fig. 1 shows the results obtained on the three nights, and also includes a lunar spectrum obtained on December 16. Atmospheric transmission data also exist from observations of Venus, obtained in December 1976. We had

hoped to repeat these observations, but were unable to carry them out during the course of the December 1977 series. This lack of adequate calibration data is the most severe limitation on the accuracy of the intensities we are able to quote. Repetition of the observations should lead to appreciably more reliable data, since our instrument is inherently capable of higher sensitivity than our present error estimates would suggest.

Line Strength and Position

After correction for atmospheric absorption of the continuum radiation emitted by Orion at the position of the 51.7μ atmospheric absorption feature, we find the following: at two adjacent positions of the grating, an increase of approximately 30% above the continuum flux from Orion is observed and must be attributed to the (O III) line. The line strength predicted on the basis of calculations by Simpson (1975) and knowledge of the (O III) 88μ line flux (Paper I) would lead to a ~22% increase, which is in reasonable agreement with our observations. Considering the close agreement between theory and observations found for the 88μ emission from several different H II regions (Paper I), this new result provides further evidence that the theoretical considerations seem to give a correct accounting of the processes involved in fine structure transitions in ionized nebulae.

Based on the continuum observations previously reported by Ward et.al. (1976), the observed line flux amounts to 5×10^{-15} watt cm^{-2} . The uncertainty in this line flux is probably considerably less than 50%. The main source of uncertainty comes from a lack of

precise information about the separation between the (O III) 51.8μ line and the atmospheric 51.7μ water vapor feature. Further uncertainty involves the absolute flux from the Orion continuum.

Our spectral bandpass was 0.35μ , and the grating was stepped with a step size of 0.168μ . The starting position of the grating, however, was not identical for all spectral passes taken and the spectrum was therefore effectively sampled at somewhat closer intervals than 0.168μ .

Referring the position of peak emission to the atmospheric 53.1 , 51.7 and $51.4_5\mu$ features, we find that the (O III) line must be close to the predicted 51.8μ position, and clearly separated from the 51.7μ water vapor absorption. This latter feature actually lies closer to 51.67μ and therefore may lie almost a full grating step from the 51.8μ emission line. This is well verified by the appearance of the raw spectra we obtain. The 51.8μ feature generally appears in two adjacent grating positions, as expected. In the position that lies at shorter wavelengths, however, the observed line intensity is lower--in agreement with expectations derived from the lunar calibration which shows atmospheric absorption at this position. In contrast, the grating position at which the peak (O III) flux is observed shows little or no absorption in the lunar spectrum. These data strongly support our contention that the (O III) line must be well separated from the atmospheric water vapor feature, possible by as much as a full step size of 0.168μ and places the (O III) line at 51.8μ as predicted.

Line Strength Errors

The estimation of the actual line strength is made difficult by the proximity of the expected 51.8μ line to the atmospheric water vapor absorption feature at 51.7μ . Traub and Stier (1976) have analyzed the expected atmospheric absorption spectrum at airplane altitudes and find roughly equally strong absorption features at 51.7 and 51.4μ , a saturated feature at 53.1μ and a weak feature at 51.1μ . All these lines are quite narrow, ($\sim 0.05\mu$) and the probability of a chance coincidence between the even narrower (O III) transition and one of these lines is therefore less than one in four. We can, however, rule out the probability for this coincidence even further.

Let us look at the schematic diagram Fig. 2. The probability for including both the (O III) line and the 51.7μ water vapor absorption feature in one and the same spectral resolution element is quite high, even though the exact coincidence of the two lines--and therefore the absorption of radiation in this line feature--is low.

Our observations, however, show a line flux to continuum ratio of approximately 30% integrated over the resolved wavelength interval surrounding the emission feature. In contrast, the expected absorption of Orion continuum radiation is relatively small. In the 0.35μ spectral band pass, absorption by the 51.7μ water vapor feature alone is less than $\sim 10\%$, and the absorption by both the 51.4_5 and the 51.7μ features included in a single spectral resolution element would be below 25%. Spectra of the Moon confirm that the total absorption due to these lines in any spectral range covered is never greater than 15-20%.

The range of elevation angles over which observations can be carried out from the Lear Jet lies in the interval between 14° and 26° . In a typical flight during the series conducted in December 1977 we covered roughly half this range, a range corresponding to a difference of about one air mass. On the flights of Dec. 6, 8 and 14, the ranges were respectively 18° - 22° , 15° - 22° and 17.5° - 22.5° . The water vapor content of the atmosphere of course varies as the aircraft flies its course, and hence the atmospheric water vapor content along the line of sight need not monotonically decrease as Orion's position rises above the horizon. Nevertheless, we plotted our data as a function of increasing horizon angle for each of the three nights on which Orion was observed. We obtained 5, 6, and 4 scans of the source, respectively on Dec., 6, 8 and 14, 1977.

This series of plots shows no systematic trends with increasing horizon angle--neither in the strength of the water vapor absorption feature nor in the strength of the O III line.

We interpret this result in the following way: the absorption at the center of the water vapor bands is nearly saturated and will not change a great deal when the water vapor content above the plane decreases slightly. The contribution to the total absorption in the wings of the line decreases somewhat, but this decrease is too small to be noted in the presence of random variations in atmospheric water vapor content.

Discussion

The discovery of the 51.8μ (O III) line has, we believe, considerable significance for future observations in the far infrared. We had found, in Paper I, that the 88μ line intensities observed in many H II regions lie close to values that can be predicted on the basis of radio observations of these nebulae. Discrepancies were found, however--particularly for the Galactic center regions SgrA and SgrB2. According to Erickson et.al. (1977), some amount of absorption might be expected even at wavelengths as long as 100μ for SgrB2, and if this turns out to be correct, it should be possible to combine radio data on conditions in the ionized gas, with 51.8μ and 88μ line observations, to estimate the relative absorption of dust at these two far infrared wavelengths. Such observations could be valuable in determining whether the far infrared extinction of dust follows a λ^{-1} , a λ^{-2} dependence, or neither of these. Currently there is essentially no concrete information available on this wavelength dependence. Such data are required to permit better estimates of cloud temperatures, and to promote better understanding of the nature of dust in dense interstellar clouds.

For regions that are not heavily obscured, the two far infrared lines can be used to determine the concentration of electrons more accurately. In particular the differences in observed line intensities and calculated intensities computed on the basis of radio data can be used to obtain a measure of clumping in the H II domain. This comes about because of collisional deexcitation of the ions, which depends on the electron

density n_e . In contrast, radio free-free emission is proportional to n_e^2 integrated along the line of sight. The difference permits an estimate of the clumpiness of the region.

The good agreement obtained between theoretical and observed line strengths in the Orion Nebula, in fact suggest that the clumpiness of the nebula is not extreme. Otherwise our observed line strengths could not be readily predicted on the basis of radio continuum intensities alone.

Acknowledgements

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References

Dain, F. W., Gull, G. E., Harwit, M. and Ward, D. B., 1978,

Ap.J. Letters, in press.

Erickson, E. F., Caroff, L. J., Simpson, J. P., Stecker, D. W.

and Goorvitch, D., 1977, Ap.J. 216, 404.

Greenberg, L. T., 1977, private communication.

Petrosian, V., 1970, Ap.J. 159, 833.

Simpson, J. P., 1975, Astr.Ap. 39, 43.

Traub, W. A. and Stier, M. T., 1975, Ap. Optics, 15, 364.

Ward, D. B., Dennison, B., Gull, G. E. and Harwit, M., 1976,

Ap.J. Letters, 205, L 75.

Figure Captions

Fig. 1. The 52μ spectral regions measured for the Orion Nebula, the Moon and Venus. The expected (O III) feature lies at 51.8μ , where the top three curves show a distinct peak. The error bars are smaller than the sizes of the dots on all three curves. In the top three curves, differences obtained from one observing run to the next can be attributed to slight changes in the grating positions on different days. These can be calibrated out more accurately by reference to atmospheric water vapor features. However, since we were unable to obtain data on the full set of atmospheric calibration flights on which we had planned, this calibration cannot be fully carried out with the present data set, and provides the single most important limitation on our accuracy.

Fig. 2. Schematic diagram of the atmospheric absorption spectrum at airplane altitudes, taken from computations by Traub and Stier (1975). We also show the spectral resolution of our instrument, the grating step size and the expected (O III) line position.

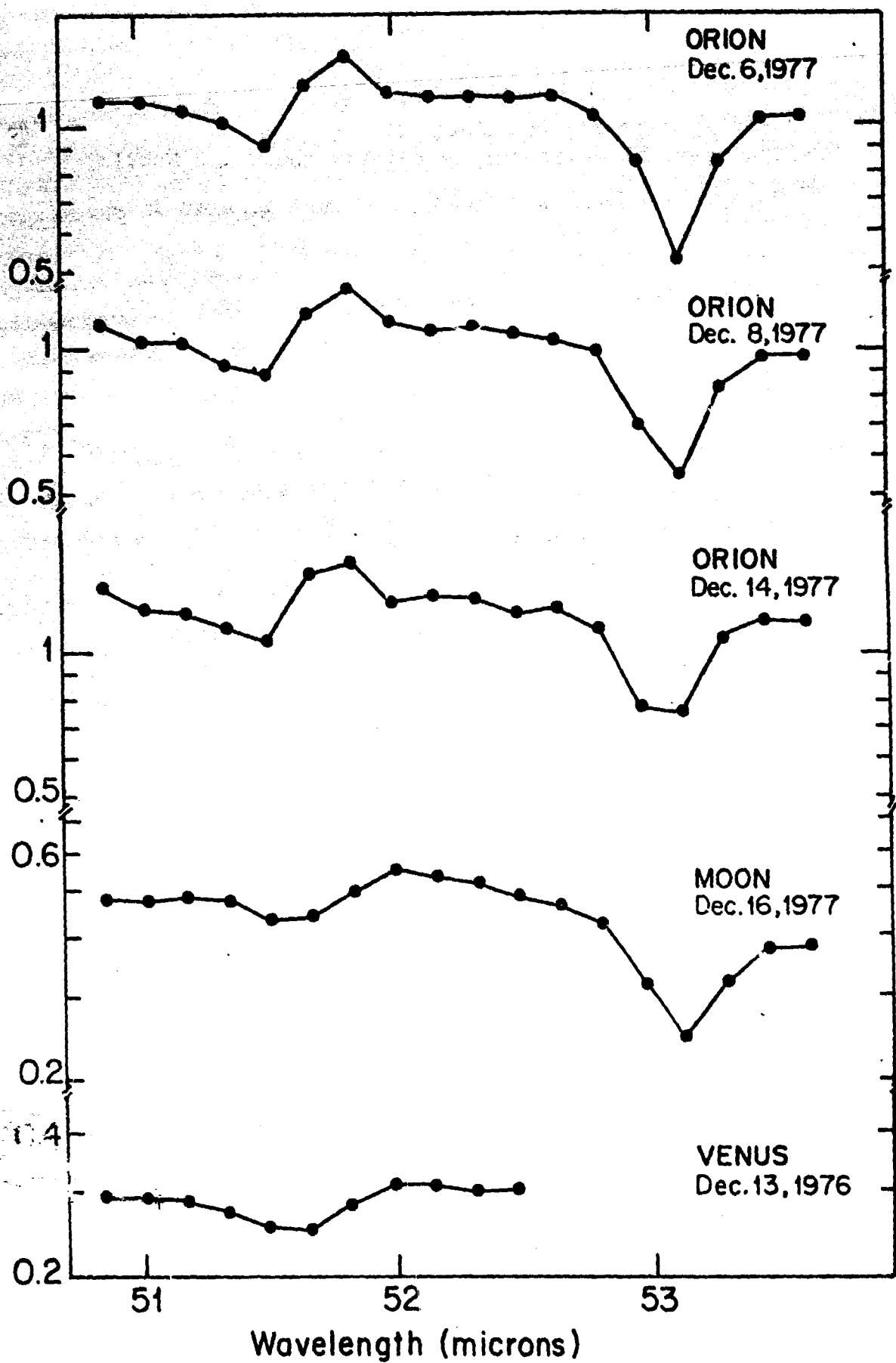


Figure 1

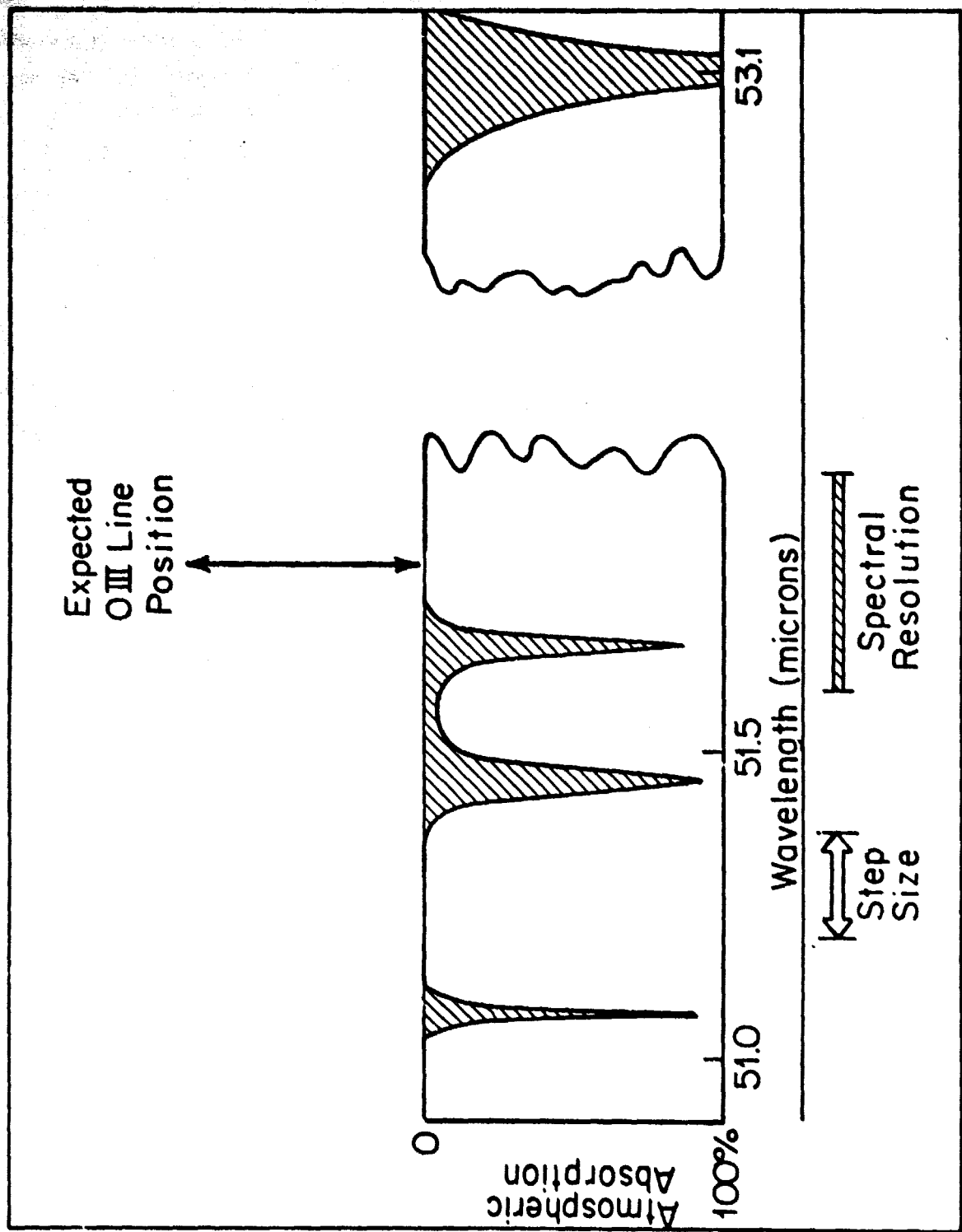


Figure 2